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NASA Project Apollo Working Paper No. 1037

PROJECT APOLLO

REDUCTION OF NULLS IN C-BAND BEACON ANTENNA PATTERN IN SUPPORT OF MERCURY AND APOLLO PROGRAMS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

Langley Air Force Base, Va.

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IN SUPPORT OF MERCURY AND APOLLO PROGRAMS

SUMMARY

A method for modifying the C-band beacon to eliminate the nulls in the antenna pattern experienced in the Mercury program is presented in this report. A sensing device is used to determine which antenna of a multiple antenna system receives the strongest signal at any instant of time. The transmitter is then connected to that antenna. A typical diversity system samples the AGC voltage in each receiver and connects the transmitter to the antenna receiving the strongest signal over a period of time. The approach taken in this study is to compare each pulse received simultaneously from the antennas and determine which antenna receives the strongest signal at any instant of time. If antenna "A" receives the strongest signal at a time when T = 0, the transponder will reply on antenna "A." If antenna "B" receives the strongest signal when T = 100 microseconds, then the transponder will reply on antenna "B." A coaxial crystal switch is used to connect the transmitter to the proper antenna with switching time in nanoseconds. (Ref. 1).

The advantages of such a system are as follows:

(a) Simultaneous reception from all antennas without the nulls in the antenna pattern

(b) Redundancy by having multiple receiving channels instead of one

(c) The total transmitter power is concentrated into one antenna instead of being divided between the three antennas as in the Mercury program.

(d) Increased range by virtue of paragraphs (a) and (c) above

(e) Several synchronized radars can maintain simultaneous tracking, and when one radar loses track, a radar further down range can maintain contact without interruption, if the two radar coverages overlap.

The only disadvantage is the increase in size and complexity of the present system. However, the added electronics is offset by the redundancy mentioned in paragraph (c) and also by virtue of a far superior system.

A comparison is made in table I between the existing system and a modified system as proposed in this report. (Ref. 2).

INTRODUCTION

The present C-band beacon used in Project Mercury and being proposed for Project Apollo has three antennas which receive and transmit simultaneously. The antenna pattern has nulls that are as much as 20 decibels down. Figures 1 and 2 are typical plots of the present system antenna patterns. An interrogating radar has difficulty tracking the capsule at long ranges because of these nulls. (Ref. 3).

Tests are now being conducted to minimize these nulls by varying the phase of one of the three antennas at a 400-cycle rate. Tests are not complete to determine the effectiveness of this wobulator technique, but radiated power is still being wasted by transmitting in all directions simultaneously.

Several techniques were investigated that could be used to minimize or eliminate the nulls in the antenna pattern and at the same time utilize the transmitter output power more effectively. The latter problem required that the system would have to know the direction of the interrogating radar. This necessitated a comparator to determine which antenna receives the strongest signal and responding via that antenna. Since there are no unwanted nulls when transmitting on only one antenna, the only problem is simultaneous reception on more than one antenna. This problem can be solved by having a receiver for each antenna and combining the outputs after detection. This eliminates any microwave phasing problems which are the cause of the nulls in the antenna pattern.

The above premises left only the method by which to accomplish the desired results. The two methods discussed in this report are as follows:

(a) Multiantenna reception and ferrite switching

(b) Multiantenna reception and solid-state switching

MULTIANTENNA RECEPTION AND FERRITE SWITCHING

Figure 3 is a functional block diagram of a modified C-band beacon utilizing a receiver for each antenna, a ferrite circulator and standard diversity techniques. By comparing the AGC level in each receiver against a reference, the system will detect when the signal level is dropping off in a particular channel. The logic circuitry will determine which antenna has preference when more than one channel has an AGC level which is above the reference level. Once the transmitter is connected to a particular antenna, the ferrite switch will remain in this position until the AGC level in the respective receiver drops below the reference level. If the AGC level in another channel is above the reference level, the transmitter will be switched to the corresponding antenna. Switching time is in the order of 8 to 10 milliseconds. The logic circuit is such that no two antennas can be simultaneously connected to the transmitter.

The output of the drivers are differentiated and the leading edge delayed by an amount equal to the switching time. The leading edge pulse then sets a flip-flop which enables a gate to allow the transmitter to be triggered. The trailing edge of the driver pulse resets the flip-flop and disables the gate which prevents triggering the transmitter. This circuitry is required to prevent triggering the transmitter during the transfer of the ferrite circulator from one antenna to another.

This system has all the advantages stated in the "Summary" section with the exception of (e). If the tracking radars are in such a position with respect to the capsule that they do not interrogate the same antenna, only one radar can maintain track. The other radars will not be able to track the vehicle unless the signal strength of the first radar falls off or the position of the spacecraft changes such that both radars can interrogate the same beacon antenna.

The disadvantages of this system are as follows:

(a) Difficulty in tracking with more than one radar as mentioned above

(b) Ferrite circulators are heavy. A four-port circulator (1P3T) weighs 3 to 4 pounds.

(c) A high current and high voltage pulse is usually required to operate such a device in the C-band.

Investigations have been made to locate a faster operating ferrite device. Ferrotec, Inc., Newton, Massachusetts manufactures a unit with switching time proportional to the power that can be delivered by the driver that performs the switching function. The inductance of the ferrite switch is 100 millihenries. According to the formula, $e = -L \frac{di}{dt}$, a 300-volt, 125-milliampere pulse would be required in order to operate the switch in approximately 50 microseconds. This means that a larger power supply and driver is required in order to obtain any speed from the device.

MULTIANTENNA RECEPTION AND SOLID-STATE SWITCHING

Figure 4 is a functional block diagram of a modified C-band beacon utilizing a receiver for each antenna, a diode switch and a comparator which determines which antenna is receiving the strongest signal. The principal of operation is similar to that described in the "Multiantenna Reception and Ferrite Switching" section except that the actual signals are compared instead of the AGC levels. A three-antenna system is shown and the detected outputs of the three channels are compared in the comparator, which consists of three differential amplifiers. The output of the differential amplifiers will be either positive or negative depending on which signal is the strongest. (See fig. 4(a).) Table II shows the various combinations of relative signal strengths and their effect on the comparator and logic circuitry. Antenna "A" will respond any time that the input to the logic circuitry has "A" - "B" = 0 and "C" - "A" is negative. Antenna "B" will respond when "A" - "B" is negative and "B" - "C" = 0. Antenna "C" will respond when "C" - "A" = 0 and "B" - "C" is negative.

As shown in table II, when "A" and "B" are equal, only antenna "A" will respond. When "A" equals "C," only antenna "C" will respond, and so forth. The logic circuitry consists of three amplifiers, three flip-flops and three drivers for the antenna selector. Either the trailing edge of the transmitted pulse can be used to reset the flip-flops or a separate one-shot can be used for a master reset. These bistable multivibrators are interlocked such that no two antennas can be connected to the transmitter simultaneously during transmission. The detected outputs of the receivers are added and fed into the decoder. In order to prevent the transmitter from being triggered without the antenna selector being energized, the inputs to the selector are "or'd" together and the output then enables another gate to allow the driver signal to trigger the modulator. Therefore, a signal has to be present at the input to the antenna selector before the transmitter can be pulsed.

When adding the detected outputs of the receivers, there will be a deterioration in the signal-to-noise ratio in some instances. The video signals will add directly, but the noise adds as the square root of the sum of the squares. Therefore, the output of the adder will follow the formula:

$$\frac{e_o}{n_o} = \frac{e_1 + e_2 + e_3}{\sqrt{n_1^2 + n_2^2 + n_3^2}}$$

Where:

$\frac{e_o}{n_o}$ is the signal-to-noise ratio at the adder output

$e_1 + e_2 + e_3$ is the sum of the three video inputs

n_1, n_2, n_3 are the respective noise levels in each channel.

For simplicity, let $n_1 = n_2 = n_3 = n$, we then have:

$$\frac{e_o}{n_o} = \frac{e_1 + e_2 + e_3}{n\sqrt{3}}$$

When a signal is present in only one channel, the S/N ratio decreases. But as another channel starts to receive a signal, the S/N ratio improves. Where two channels receive the same signal level, we have the following:

$$e_1 = e_2$$

$$n_1 = n_2 = n_3$$

$$\text{S/N at output of channel 1} = \frac{e_1}{n_1} = \frac{e_2}{n_2}$$

$$\text{S/N at output of adder} = \frac{e_1 + e_2}{\sqrt{n_1^2 + n_2^2 + n_3^2}} = \frac{2e_1}{n_1\sqrt{3}} = \frac{e_1}{n_1}\left(\frac{2}{\sqrt{3}}\right)$$

In order to prevent deterioration of the S/N ratio when only one channel is receiving a signal, a squelch circuit could be incorporated at the output of each receiver, in which case, there would be no noise at the output of any channel until there was a signal present in the respective channel.

FUTURE APPLICATIONS

Future Mercury capsules can improve the tracking capabilities of the FPS-16 radar by elimination of the nulls in the antenna pattern and increasing the radiated power of the beacon by a factor of three in the desired direction.

Greater power is required in the Apollo program than in the Mercury program. Ignoring the nulls in the antenna pattern, the beacon power with the present system would have to be three times the power of the proposed modified beacon for the same effective antenna output.

Figures 5 to 11 are block diagrams representing the various system configurations that could be used for the Apollo vehicle. Systems 1 and 2 use four beacons. Therefore, if one beacon fails, only a small sector of the total antenna pattern will be affected. If Mercury-type antennas are used, this sector would be approximately 60°. In systems 3, 4, 5, 6, and 7 more redundancy may be required for high reliability. This could amount to just carrying a spare beacon. When notified by the ground station or some other means of failure detection, the crew could then install the spare beacon or reconnect the cables if the two beacons are located adjacent to each other. To have this done automatically would entail excessive weight and RF losses due to the switches and cables that would be required.

Table III compares the various systems depicted in figures 5 to 11. Where multiple beacons are used, the primary power could be further reduced by using a common power supply. This would make a great improvement in systems 1 and 2. The input power could be reduced from 120 watts to approximately 80 watts. For redundancy, this could be a dual supply with only one supply operating at a time.

REFERENCES

1. Damon, Richard W.: Solid State Control of Microwaves. Military Systems Design, vol. 5, no. 4, Jul.-Aug. 1961, pp. 21-22.

2. Anon.: Handbook for the Manned Astronautic Communications Subsystem. McDonnell Aircraft Corp., MAC-133, Jan. 15, 1960.

3. Towey, James M.: Accuracy of C-Band Radar Tracking. Memo to Chief, Flight Systems Division, NASA Space Task Group, Langley Field, Virginia, Jun. 30, 1961.

TABLE I.- SYSTEM LOSSES OF MODEL 149-C BEACON VS. MODIFIED BEACON OVER A 700-NAUTICAL-MILE DISTANCE

	Model 149-C beacon assuming no antenna nulls		Model 149-C beacon with 20 db antenna nulls		Modified model 149-C beacon	
	To vehicle	From vehicle	To	From	To	From
Xmtr. output power (P_T)	54.0 dbw	25.7 dbw	54.0 dbw	25.7 dbw	54.0 dbw	25.7 dbw
Xmtr. cable loss (L_{CT})	-2.0 db	-2.2 db	-2.0 db	-2.2 db	-2.0 db	-2.2 db
Xmtr. antenna gain (G_T)	+44.0 db	-8.0 db	+44.0 db	-28.0 db	+44.0 db	+1.2 db*
Loss in free space	-171.0 db	-171.0 db	-171.0 db	-171.0 db	-171.0 db	-171.0 db
Rec. antenna gain (G_R)	-8.0 db	+44.0 db	-28.0 db	+44.0 db	+1.2 db*	+44.0 db
Rec. cable loss (L_{CR})	-2.6 db	-2.0 db	-2.6 db	-2.0 db	-2.6 db	-2.0 db
Pwr. at rec. input (P_R)	-85.6 dbw	-113.5 dbw	-105.6 dbw	-133.5 dbw	-76.4 dbw	-104.3 dbw
Receiver sensitivity	-95.0 dbw	-125.0 dbw	-95.0 dbw	-125.0 dbw	-95.0 dbw	-125.0 dbw
Actual margin	+9.4 db	+11.5 db	-10.6 db	-8.5 db	+18.6 db	+20.7 db
Desired margin	+10.0 db	+23.0 db	+10.0 db	+23.0 db	+10.0 db	+23.0 db

*Average measured value of three individual antennas.

TABLE II.- ANTENNA SIGNAL STRENGTHS VS. TRANSMITTING ANTENNA

Antenna signal strengths			Output of comparator			Input to logic (after the diodes)			Receiving antenna with strongest signal	Transmitting antenna
A	B	C	A-B	C-A	B-C	A-B	C-A	B-C		
0	0	0	0	0	0	0	0	0	no signal	
0	0	3	0	+	-	0	0	-	C	C
0	3	0	-	0	+	-	0	0	B	B
3	0	0	+	-	0	0	-	0	A	A
0	1	2	-	+	-	-	0	-	C	C
1	0	2	+	+	-	0	0	-	C	C
0	2	1	-	+	+	-	0	0	B	B
1	2	0	-	-	+	-	-	0	B	B
2	1	0	+	-	+	0	-	0	A	A
2	0	1	+	-	-	0	-	-	A	A
1	1	0	0	-	+	0	-	0	A=B	A
1	0	1	+	0	-	0	0	-	A=C	C
0	1	1	-	+	0	-	0	0	B=C	B
1	1	2	0	+	-	0	0	-	C	C
2	1	1	+	-	0	0	-	0	A	A
1	2	1	-	0	+	-	0	0	B	B

TABLE III.- COMPARISON OF VARIOUS BEACON CONFIGURATIONS

System (see figs. 5 to 11)	Average power in (watt)	Antenna peak power out (watt) (directional)	Number of antenna	Coaxial (ft)	System wt (lb)	Power out / Power in	Power out / wt (lb)	Notes
No. 1	120	748	4	8	30.4	7.8:1	31:1	1, 2, 4, 6, 13
No. 2	120	748	4	8	31.4	7.8:1	30:1	2, 3, 5, 6, 13
No. 3	60	340	4	16	19.6	7.1:1	21:1	2, 3, 4, 7, 8, 13
No. 4	31	282	4	20	15.3	11.4:1	23.1:1	2, 3, 4, 8, 9, 13
No. 5	32	578	3	10	14.9	22.1:1	47.5:1	2, 3, 5, 9, 10, 13
No. 6	30	748*	1	2	12.3	—	—	2, 3, 9, 11, 12, 13
No. 7	33	492	4	24	19.1	17.8:1	31:1	2, 3, 5, 6, 13

*Omnidirectional

Notes:

1. More than one antenna may respond to an interrogating signal.
2. No nulls in receiving antenna pattern.
3. No nulls in transmitting antenna pattern.
4. Assuming that the beacons are located not more than 2 to 3 feet from the antenna or power divider.
5. Only one antenna will respond to an interrogating signal.
6. Limited redundancy built in.
7. Less redundancy than systems no. 1 and no. 2.
8. Two antennas, 180° apart respond per each interrogating signal.
9. Added redundancy required.
10. Mercury antenna configuration.
11. Structure problems may arise.
12. Omnidirectional antenna has to be developed. Assumed weight = 5 pounds
13. All beacons are ACF type 151 beacons or modified type 151 to include the comparator, (800-watt peak power output, and 7 pounds each).

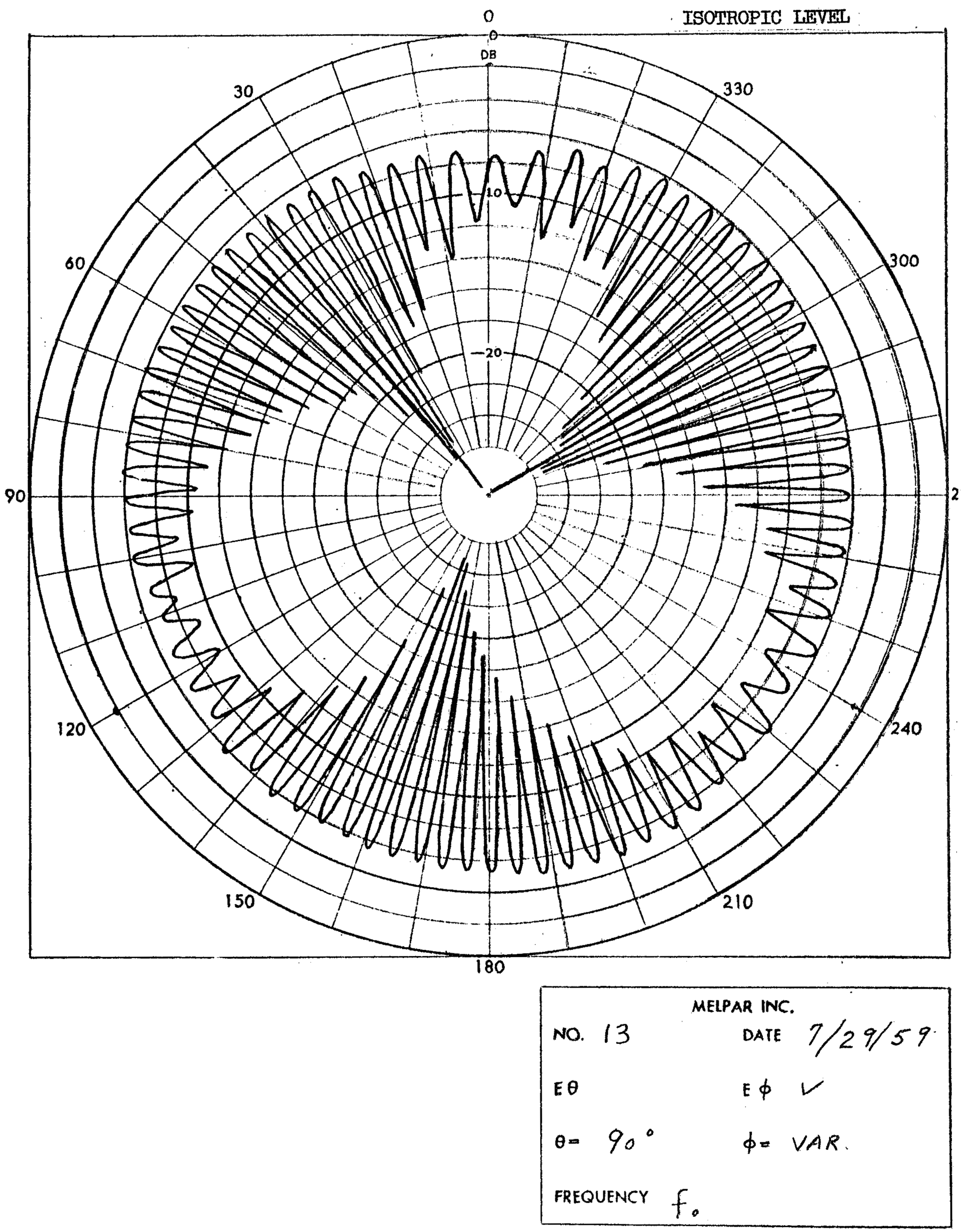


Figure 1.- Mercury C-band antenna system.

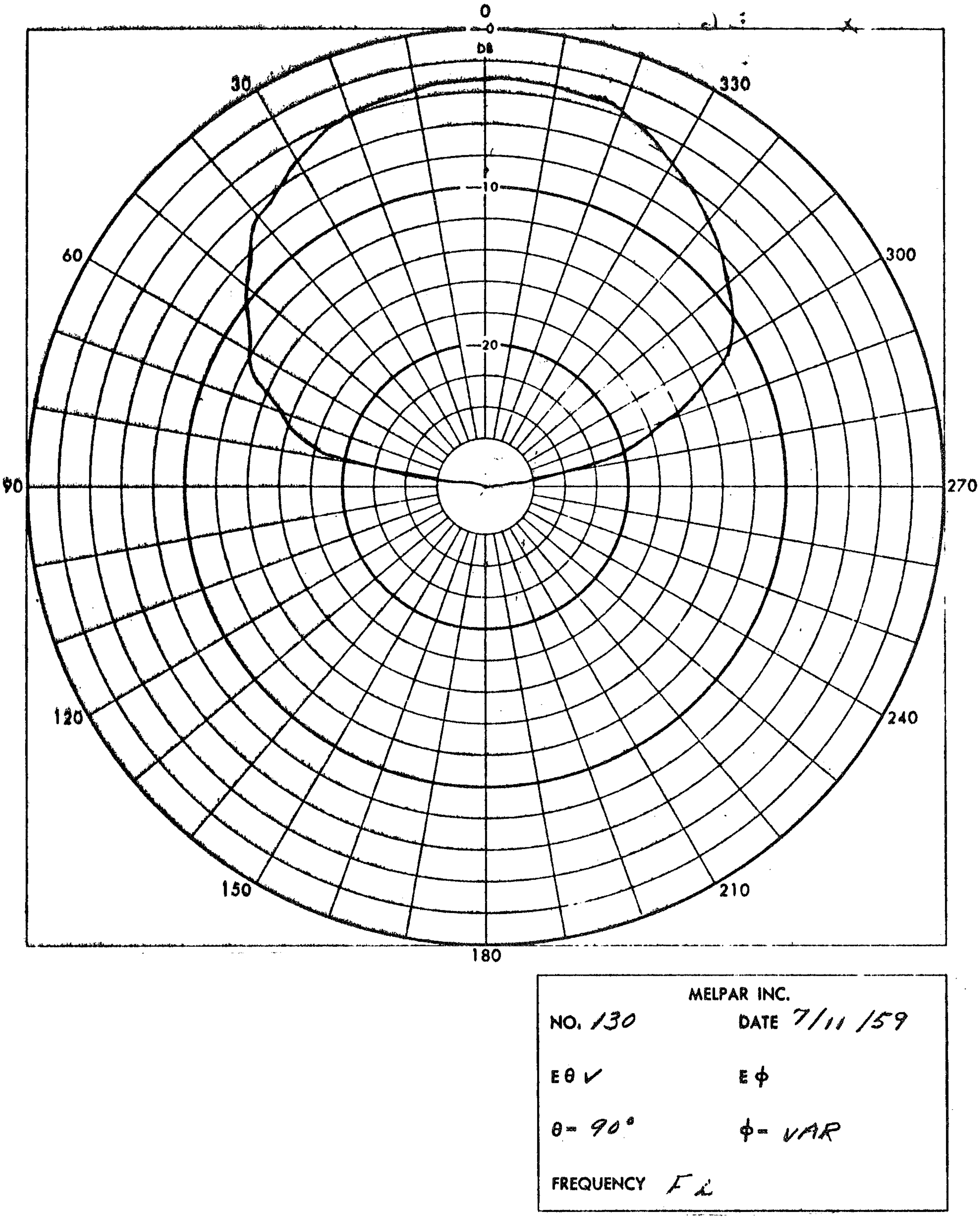


Figure 2.- Antenna single unit number 2.

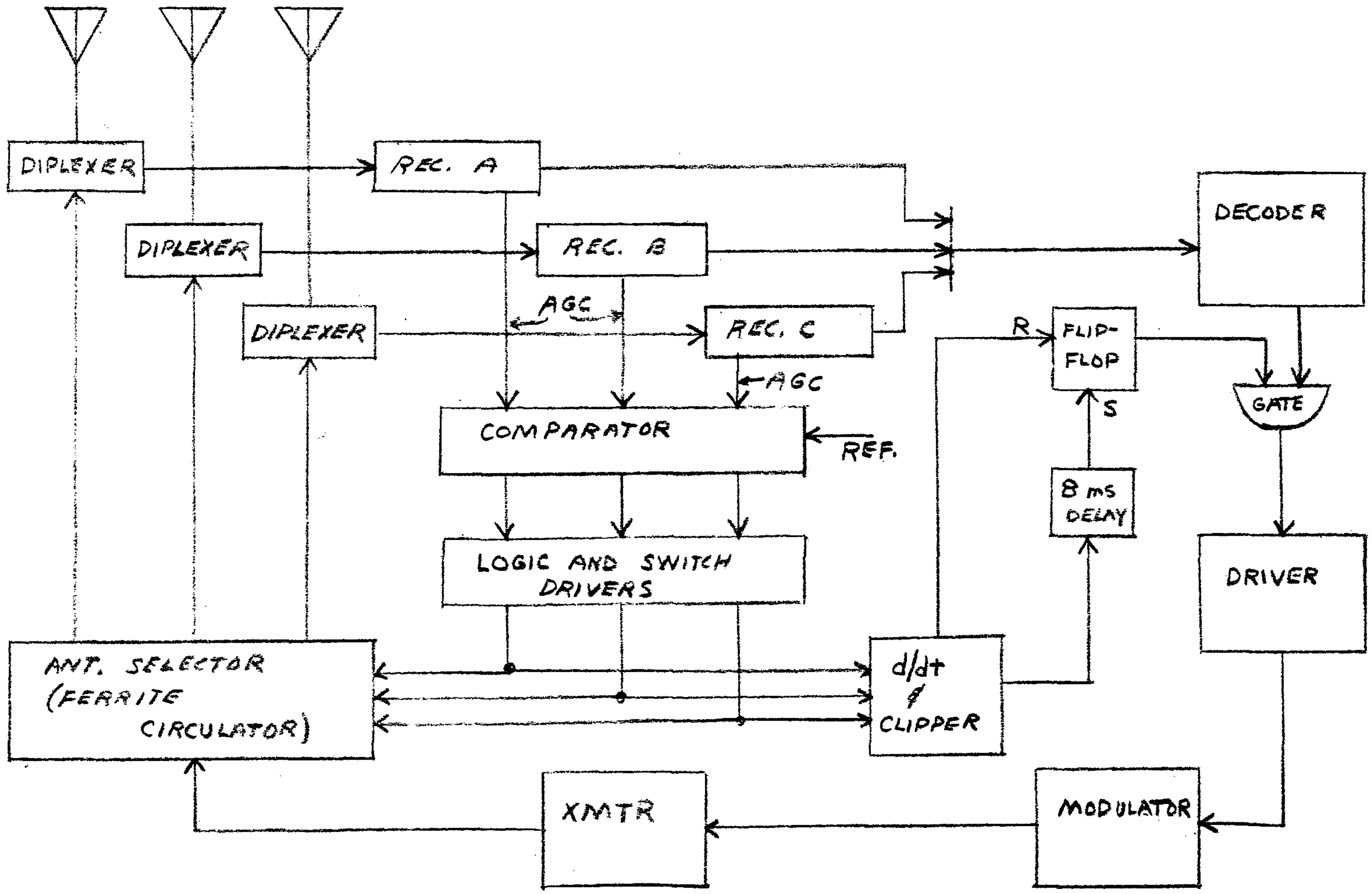
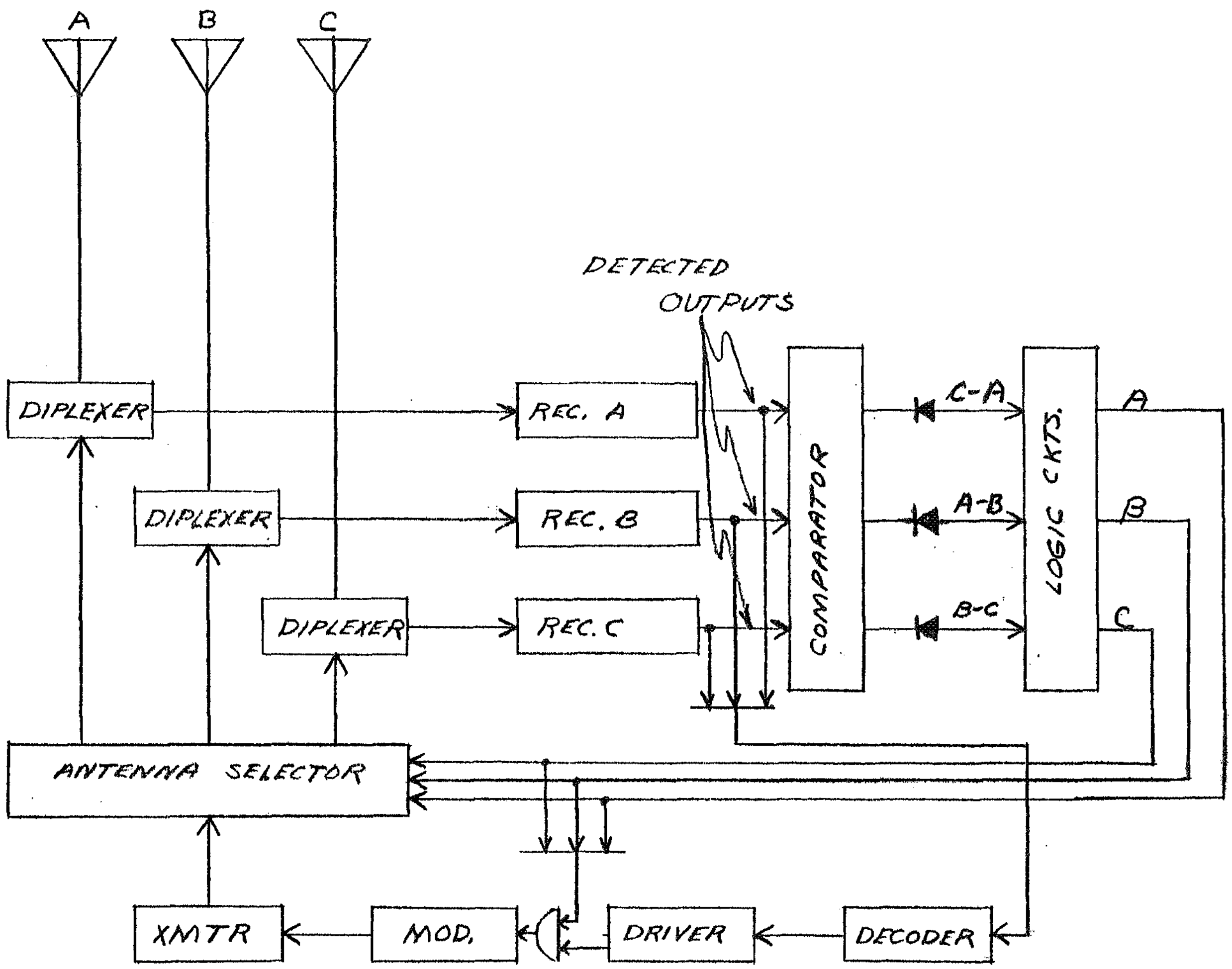


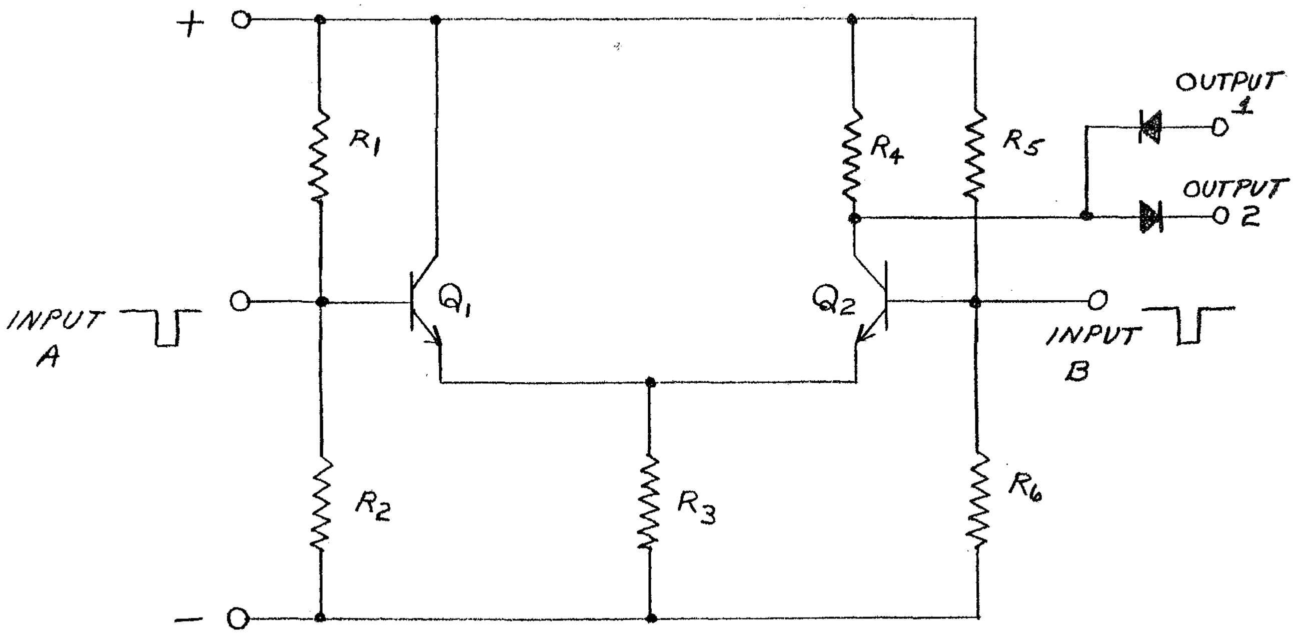
Figure 3.- Functional block diagram of modified C-band beacon with a ferrite circulator.



ANT. WITH STRONGEST SIGNAL	A - B	C - A	B - C	TRANS. ANT.
A	O	–	– OR O	A
B	–	– OR O	O	B
C	– OR O	O	–	C
A = B	O	–	– OR O	A
B = C	–	– OR O	O	B
A = C	– OR O	O	–	C
NO SIG.	O	O	O	

(a) Functional block diagram.

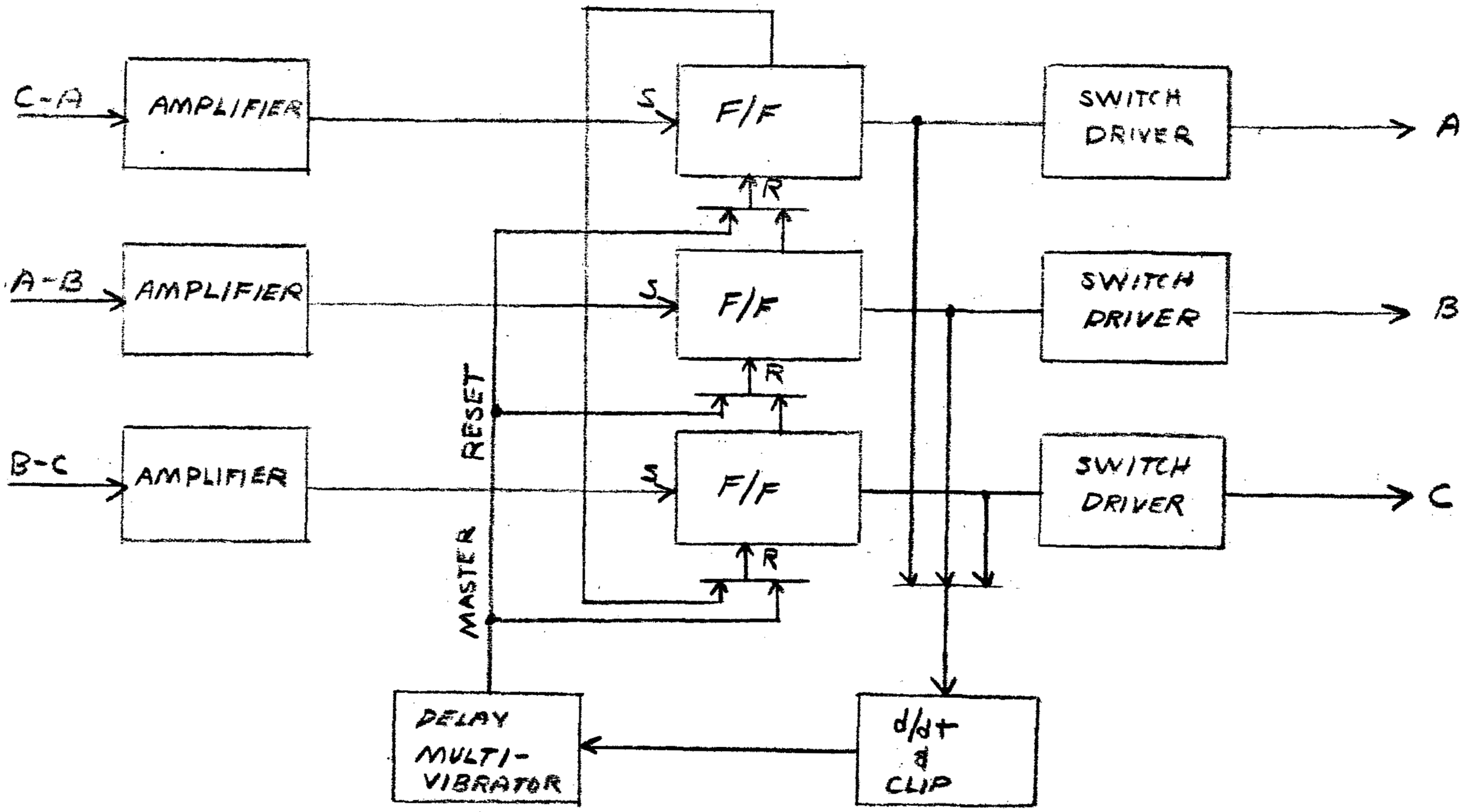
Figure 4.- Modified C-band beacon with a solid-state antenna selector.



INPUT	Q2 COLLECTOR	OUTPUT 1	OUTPUT 2
NO SIG.	QUIESCENT	0	0
A > B	NEGATIVE	NEGATIVE	0
A ∠ B	POSITIVE	0	POSITIVE
A = B	QUIESCENT	0	0

(b) Typical differential amplifier in the comparator circuit.

Figure 4.- Continued.



(c) Logic circuits.

Figure 4.- Concluded.

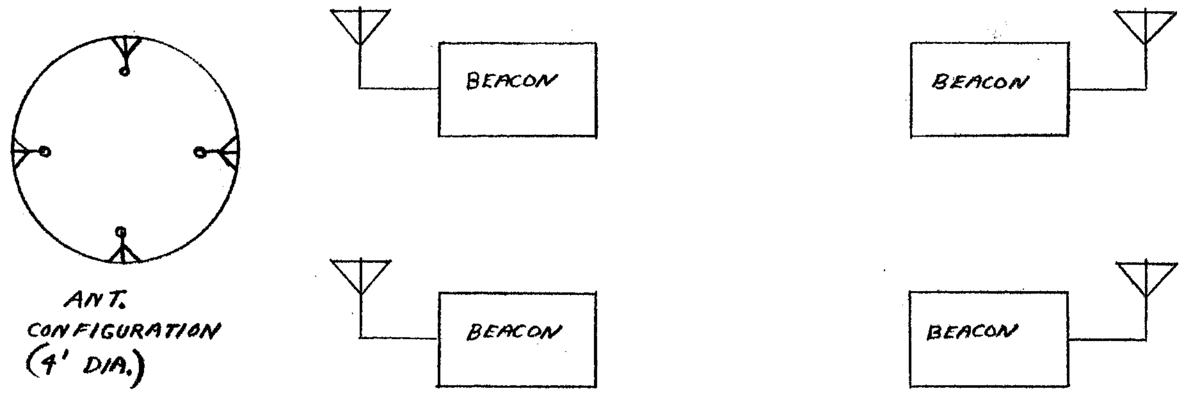


FIG. 5 – APOLLO BEACON SYSTEM #1

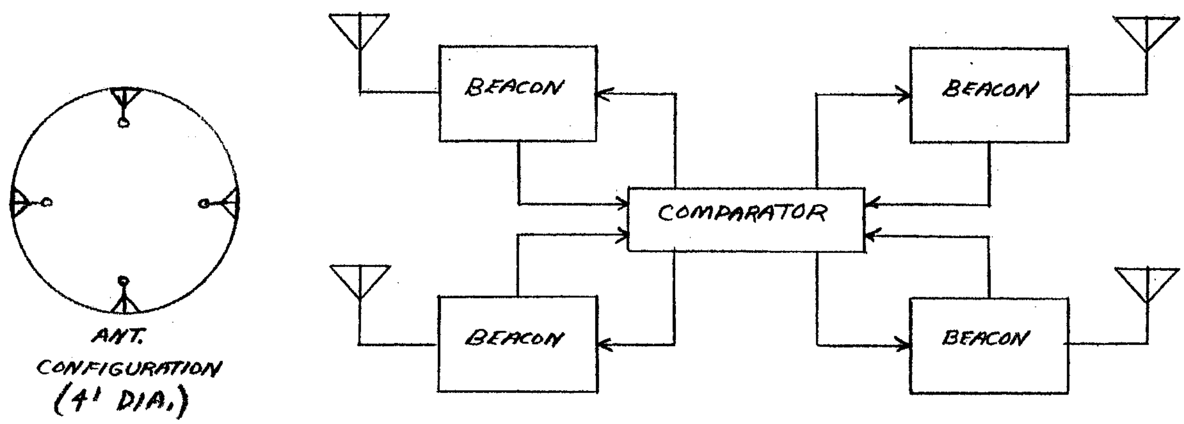


FIG. 6 – APOLLO BEACON SYSTEM #2

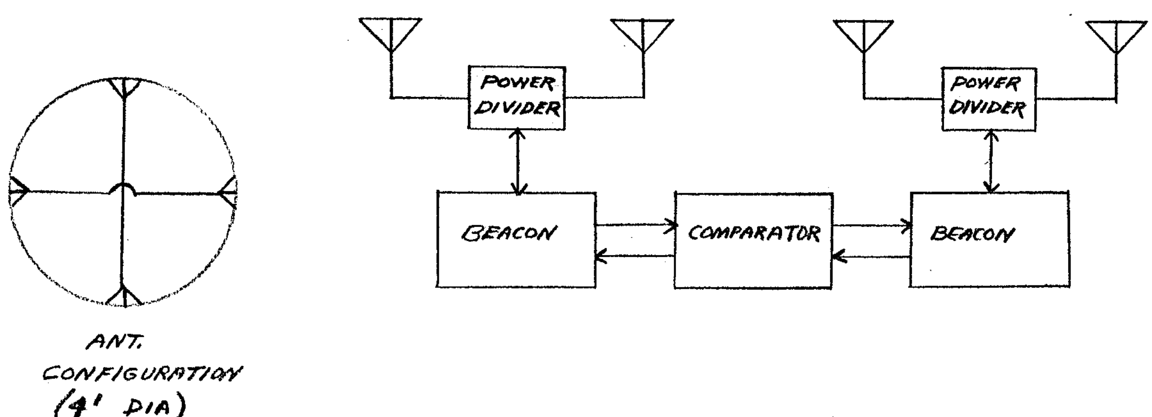


FIG. 7 - APOLLO BEACON SYSTEM #3

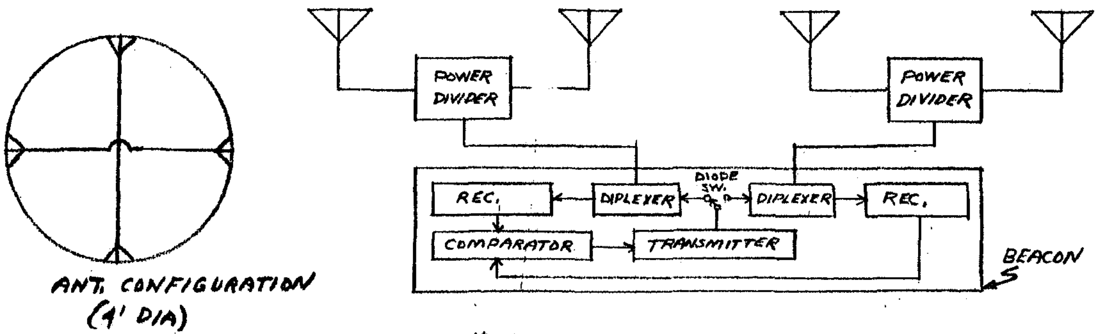


FIG. #8 - APOLLO BEACON SYSTEM #4

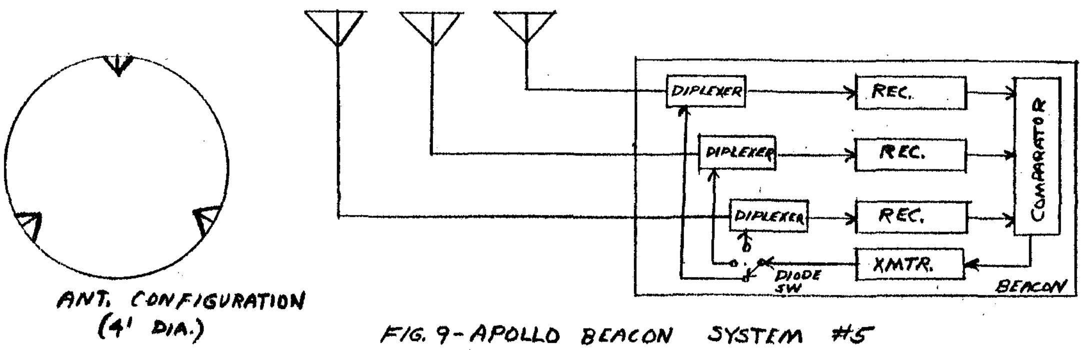


FIG. 9 - APOLLO BEACON SYSTEM #5

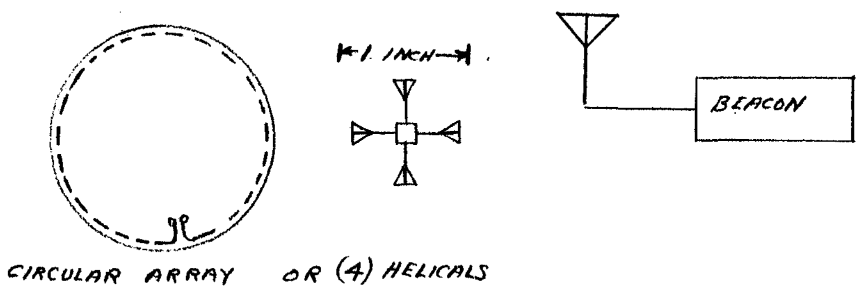


FIG 10 - APOLLO BEACON SYSTEM #6

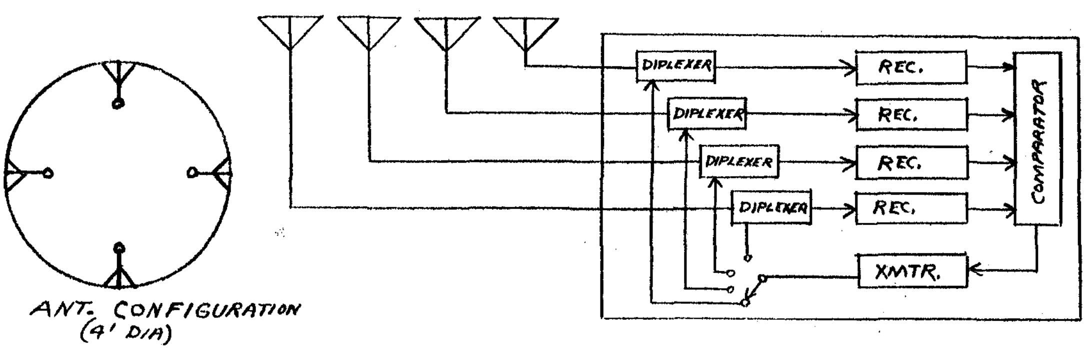


FIG. 11 - APOLLO BEACON SYSTEM #7